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UNITED STATES DEPARTMENT OF AGRICULTURE

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Washington Agricultural Experiment Station

DEPARTMENT BULLETIN No. 1239

Washington, D. C. ▼ May, 1924

STUDIES IN THE PHYSIOLOGY AND CONTROL OF BUNT, OR STINKING SMUT, OF WHEAT

By

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PHYSIOLOGIC FACTORS AFFECTING THE DEVELOPMENT OF BUNT.

The studies reported here were carried on by the writers from 1913 to 1921. Although these studies are by no means exhaustive it is believed that, in so far as they are conclusive, they will contribute materially to our knowledge of the relation of various factors to bunt infection, to the life history of the organism, and to methods of control of the disease.

At the time the field experiments herein reported were begun at Pullman, Wash., it had become evident that the bunt of wheat in the principal wheat districts of the Pacific Northwest could not be controlled by seed treatment. Approximately all the wheat growers of this region were giving their seed as severe a treatment, following approved methods, as was possible without destroying its viability. In spite of this, 25 per cent of bunt was not uncommon and 50 per cent or more was sometimes observed. In general, the strength of

[1] The research the results of which are recorded in this bulletin was conducted by the Office of Cereal Investigations of the Bureau of Plant Industry in cooperation with the Washington Agricultural Experiment Station. The writers wish to make special acknowledgment to Profs. F. D. Heald and E. F. Gaines, of that station, for their many helpful suggestions and to Dr. Erwin F. Smith, of the Bureau of Plant Industry, who made possible the soil temperature studies herein reported by placing at the disposal of the junior writer the special-compartment incubator of the laboratory under his care.

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solution and duration of immersion of the seed were largely guesswork, particularly where copper sulphate was used and in those sections where the smut losses were heaviest. Years of experience, however, had convinced the growers that copper sulphate gave them better results than formaldehyde, and it finally developed that there was good reason for this view.

THE PROBLEM OF SOIL INFESTATION.

The writers faced a condition rather than a theory. The seed treatments used in the course of these investigations were designed principally to confirm the inevitable conclusion that there was soil infestation from some source. The question as to the source of this infestation then arose. Two possible answers to this question presented themselves:

(1) That this infestation originated in bunted heads left in immense numbers on the ground at harvest time. These bunted heads were found to contain viable ungerminated spores after lying in the fields for a year.
(2) That it was caused by wind-disseminated spores.

Considered in the light of the investigations of Brefeld and others, the first explanation appeared for a time to be the more tenable. On the other hand, the experiments herein and elsewhere recorded give greater weight to the second explanation.

The wheat section in which these conditions prevailed is situated in the Columbia and Snake River basins of the Pacific Northwest, extending from the foothills of the Cascade Mountains on the west to the foothills of the Bitter Root Mountains on the east and including the plateau of the Nez Perce and Camas prairies. It extends from near the Canadian border on the north to the Blue Mountains of Oregon and Washington on the south.

As a general rule the intensity of the disease increases within this area as one follows the course of the prevailing southwest winds. Thus, the heaviest losses occur in the Palouse district centering about Pullman, Wash., and Moscow, Idaho, and in the high Nez Perce and Camas plateaus lying to the east and southeast of Lewiston, Idaho. Within this general area the altitude ranges from about 500 feet near the Columbia River to 2,600 feet at Pullman and 4,000 feet in the Nez Perce district. The annual rainfall within the area of possible wheat production varies from 12 inches in the western part to 24 inches in the eastern part. The soil varies in texture from a light volcanic ash in the western part to a rather heavy basaltic clay in the higher eastern portion. Thus we have rainfall, soil density, altitude, and bunt intensity all increasing in the direction of the prevailing wind as we proceed northeastward from a point near The Dalles on the Columbia River.

As a result of the climatic differences, harvesting operations begin in the western part about July 1 to 10 and move eastward, finishing in the extreme eastern portions some time in September. There are three methods of harvesting—i. e., binding, heading, and use of the combined harvester.

The entire wheat region under consideration is summer fallowed. In the drier parts a crop is raised in alternate years. Where the rainfall is heavier, summer fallowing is practiced once in three years, winter wheat following the fallow and spring grain the winter wheat.

The Palouse region, where most of these investigations and observations were conducted, is extremely rolling, there being almost no level land. Owing to the prevailing southwest winds the hills have become dune shaped, with the steep slope on the east or northeast face, where they frequently approach an incline of 45°. These slopes are composed of fine drifted soil, which is protected from excessive evaporation and are therefore more moist and fertile than those facing the southwest.

Observations showed that the percentage of bunt was usually higher on the northeast slopes. Owing to their steepness harvesting was difficult and wasteful, and a great number of bunted heads were left on the ground. This fact apparently conformed to the first explanation of soil infestation. But these same slopes were the natural settling places for any wind-borne dust. It was also noted that bunt was especially likely to be produced on the east and north sides of brushy fence rows, thus strongly suggesting the wind as a probable agent in spore distribution. The following observations seemed to support this view, or at least were not reconcilable with the idea that the infestation came entirely from the old bunt heads:

(1) When, as occasionally happened, wheat stubble was fall plowed and sown at once, even though the previous crop had been bunty, the percentage of bunt was comparatively, and actually, low.
(2) When wheat was spring sown, the crop was almost always practically bunt free, even though a bunty crop had been harvested the previous year.
(3) During the threshing season of a bunty year one might stand on a hill and see clouds of black dust rising from every threshing machine in sight and drifting off with the wind.

In 1911 A. M. Richardson, then of Washington State College, presented evidence in an unpublished paper showing that in some cases bunt infestation had obtained from wind-borne spores. Further evidence of the same nature was furnished in the earlier controlled experiments in seed treatment on the college farm at Pullman. It was found that unless the sowing was done in late fall or late spring any and all treatments failed to give perfect control, even when sown on ground that had not produced wheat for many years. In the fall of 1913 arrangements were made with two farmers near Pullman to replow a part of their summer-fallowed fields just before seeding. In one instance the unplowed part produced in the following harvest 25 per cent of bunt and the replowed part but 3 per cent. The unplowed portion of the other field produced 7 per cent of bunt against 1 per cent in the replowed part. In the fall of 1915 a series of periodic sowings was made on land on which wheat, so far as could be learned, had never been grown. In fact, there was no possibility that this soil could become infested except by wind-borne spores. The location, a cove on a northeast slope, was a natural assembling ground for any wind-borne material. The soil was prepared for seeding in July, and the first sowing was made on July 31. After this the soil was undisturbed except for making subsequent sowings. The seed was threshed by hand from hand-picked heads taken from bunt-free plats and was treated by soaking 20 minutes in a solution of 1 pound of copper sulphate to 1 gallon of water. Sowings were made in two plats. The results are shown in Table 1. As no bunt appeared in sowings made prior to September 2, the results of the earlier sowings are omitted.

TABLE 1.—*Results of seeding wheat at successive dates, in duplicate plats, to determine soil infestation by bunt, at Pullman, Wash., in 1915.*

Date sown, 1915.	Infected plants (per cent).			Date sown, 1915.	Infected plants (per cent).		
	Plat 1.	Plat 2.	Average.		Plat 1.	Plat 2.	Average.
Aug. 21	0	0	0	Sept. 21	37.7	.....	37.7
Aug. 26	0	0	0	Sept. 23	.....	36.4	36.4
Aug. 31	0	0	0	Sept. 28	37.3	24.0	30.7
Sept. 2	.....	8.8	8.8	Oct. 3	.....	35.0	35.0
Sept. 4	20.0	31.8	25.9	Oct. 8	.....	5.9	5.9
Sept. 14	21.3	34.1	27.7	Oct. 11	14.1	12.9	13.5
Sept. 17	40.5	41.3	40.9	Oct. 18	7.6	6.3	7.0
Sept. 19	58.1	60.0	59.1	Oct. 25	.9	0	.5

In the earlier sowings it was necessary to irrigate in the row to obtain immediate growth. Fall rains began on September 7 and the soil was thoroughly wet by September 15 to 17. Contemporaneous sowings were made from the same seed lot in plats that had been hand inoculated with bunt at different times in order to determine the duration of infection conditions resulting from spores in the soil. It so happened that these plats were in an open, comparatively level spot where the wind was uninterrupted. Sowings in these plats on dates corresponding to those in Table 1 produced much less bunt, notwithstanding the fact that they had at some time been dressed with bunt, either in heads or pulverized. After the 1915 harvest was partly completed, Heald and George (*12*)[2] installed spore traps and demonstrated the fall of spores. They continued the work in 1916 (August 15). During that year the spore fall from August 15 to October 31 at the experiment plats aggregated more than 43,000 spores per square inch.

TABLE 2.—*Relation of the date of seeding to the percentage of bunt in wheat sown at intervals between August 11 and October 30, 1916.*

[The aggregate precipitations of bunt spores per square inch, as given, are those shown by spore-trap collections on approximately the same dates.]

Date sown.	Bunt-free wheat heads.	Bunted heads.		Spore-trap collections.	
				Date.	Aggregate number of spores.
		Number.	*Per cent.*		
Aug. 11	(*a*)	.....	.....	.....	.....
Aug. 24	1,712	31	1.78	Aug. 22	1,121
Sept. 1	1,352	119	8.09	Aug. 29	6,251
Sept. 4	1,173	174	12.92	Sept. 5	14,449
Sept. 8	1,205	280	18.86	.....	.....
Sept. 11	1,338	223	14.29	Sept. 12	22,610
Sept. 14	1,547	177	10.27	.....	.....
Sept. 21	836	514	38.07	Sept. 19	27,445
Sept. 25	755	339	30.99	Sept. 26	41,050
Oct. 2	422	295	41.14	Oct. 3	42,000
Oct. 6	545	111	16.92	.....	.....
Oct. 10	687	122	15.08	Oct. 10	42,547
Oct. 18	131	17	11.49	Oct. 17	42,885
Oct. 30	(*b*)	.....	.....	Oct. 24	43,022

a Not counted. *b* No plants.

[2] The serial numbers (italic) in parentheses refer to "Literature cited," at the end of this bulletin.

In 1916 a series of sowings was made under practically the same conditions as in 1915. The results are shown in Table 2, together with the collections of a spore trap located on the plat. It is worthy of mention that during the week of August 15–21 the nearest threshing operations were probably 30 miles away.

Two further experiments were made in 1915 to establish the causal connection of the wind-borne spores to soil infestation.

In the first experiment a tract of ground well situated topographically for the settling of wind-borne material was selected, and a plat 12 by 16.5 feet was covered with straw to a depth of 4 to 6 inches on September 25, 1915. This covering of straw was burned at once to destroy by heat the spores on the soil. A similar adjacent area was left as a check plat.

Three 1-rod rows were sown in the burned-over plat on September 25 and the same number in the check plat. These sowings were duplicated on October 8 and November 5. From September 25 to October 8 there was probably an additional fall of bunt spores.

The seed used was Hybrid 143 from hand-picked heads from a clean or bunt-free crop and threshed later in a clean sack. The seed was then treated 90 minutes in a solution of 1 pound of formaldehyde to 30 gallons of water. Plant counts only were made. The results are given in Table 3.

TABLE 3.—*Results obtained by sowing bunt-free seed wheat in alternate plats of heat-sterilized soil at Pullman, Wash., at intervals during the period from September 25 to November 5, 1915.*

Date sown.	Treatment.	Total plants.	Condition of plants (per cent).		
			Bunt free.	Wholly bunted.	Partly bunted.
Sept. 25	Burned	188	97.34	1.06	1.59
	Unburned (check)	134	62.60	25.27	11.94
Oct. 8	Burned	221	94.11	3.17	2.72
	Unburned (check)	219	81.73	11.87	6.40
Nov. 5	Burned	.....	100	0	0
	Unburned (check)	.....	100	0	0

There had been considerable rain prior to September 25, and it is possible that some spores were carried down into the soil out of reach of the heat. It is also almost certain that some spores fell between September 25 and October 8. At the same time some were being eliminated on the unburned control by germination and subsequent death.

In the second experiment, 1 square rod of summer fallow adjoining the plat used in the first experiment was turned with a spade on October 6, 1915, the greatest possible care being taken to bury the surface soil. It was estimated that 90 per cent of the surface soil was placed below seeding depth. This plat was sown on October 8. A control plat immediately adjoining was sown at the same time in undisturbed summer fallow. Clean seed of Hybrid 143 was used after treatment for 90 minutes in a 1 to 240 solution of formaldehyde. The sowing was made with a sterilized garden seeder, and the replowed plat was sown first. Merely a plant count was made at harvest. The yield was much the best on the replowed plat, which

showed but 0.8 per cent of the plants affected with bunt. In the check plat 17.24 per cent of the plants were entirely smutted and 7.47 per cent partially so, 24.71 per cent of the plants thus showing infection.

The prevalence of bunt in the Pacific Northwest is dependent on the summer-fallow system of farming and on the dry summers. Almost invariably the seed bed is prepared before the threshing begins. In most years rains are infrequent or entirely lacking from July 15 to early or middle September. During this period the spores settle on the dry surface and remain intact until the rains begin; then the spores begin to germinate and usually the farmer begins seeding soon after the first good rain. By this time the seed bed is thoroughly infested with the bunt organism at its optimum virulence.

Concerning the duration of infective power of the spores, it can be said that it is dependent on a combination of temperature and moisture conditions and probably also on the bacterial and fungous flora of the soil. An examination of Table 1 shows that in 1915 their infective power was practically lost by October 25, or within five or six weeks after the soil became moist.

DURATION OF VIABILITY OF BUNT SPORES IN THE SOIL.

In order to determine just how long the bunt organism may retain its infective capacity when dispersed in the soil, crushed bunt balls were worked into the seed bed on March 5, 1915. The soil was in good tilth and sufficiently moist to favor germination and infection. Seed of the Early Wilbur variety was treated two hours in a 1 to 240 solution of formaldehyde and sown on successive dates over a period of two months, during which time the conditions for infection were nearly ideal. The dates of seeding and the results are presented in Table 4.

On April 4 crushed bunt balls were worked into the soil, and 1-rod rows of Early Wilbur wheat were sown on successive dates during the period from April 4 to June 3, inclusive. The months of April and May were characterized by soil temperature and moisture conditions highly favorable to germination and infection. The seed was treated two hours in a 1 to 240 solution of formaldehyde and sown promptly after treatment. The data obtained are shown in Table 4.

It is fairly certain that under the most favorable conditions the infective power of the bunt organism is lost within 30 days, provided there are no unbroken bunt balls. As to the overwintering of free spores in the soil the results at Pullman are in agreement with those of Tubeuf (*22*, *23*), Appel and Riehm (*4*), and Steglich (*21*), that it does not occur. However, there may be exceptions. For example, if the spores were applied to a dry soil late in the fall, followed by freezing weather before precipitation, and should lie in this dry seed bed until spring, it is not only possible but probable that the spores would remain intact until spring. The spores of unbroken bunt balls and uninjured bunt heads lying on the surface of the soil suffer but little loss of viability in the course of a year. The length of time that the ball remains intact depends on soil and weather conditions. The final destruction of the testa of the bunt ball, like other vegetable matter, is greatly promoted by saprophytic fungi, two of which are especially active in the disintegration of bunt balls. One of these is a Cladosporium (perfect stage not determined), the

other an Alternaria form of a species of Pleospora. This latter fungus begins its work very early. Its mycelium will always be found, both in the testa and in the interior among the spores, in any bunt head picked up in the field shortly after harvest. In most cases it can be isolated from standing heads before harvest.

TABLE 4.—*Comparative decline in the duration of the possible capacity for bunt infection at Pullman, Wash., as shown by successive sowings of Early Wilbur wheat in soil heavily inoculated on March 5 and April 4, 1915.*

SOWINGS IN SOIL INOCULATED ON MARCH 5.

Date of sowing.	Number of plants.			Plants infected.
	Bunt free.	Wholly bunted.	Partly bunted.	
				Per cent.
Mar. 6	14	23	29	78.8
Mar. 8	14	25	10	71.4
Mar. 13	3	48	9	95.0
Mar. 22	17	77	38	87.1
Mar. 26	23	43	38	77.9
Apr. 4	44	42	42	65.6
Apr. 9	114	41	38	40.9
Apr. 18	183	11	14	12.0
Apr. 24	127	2	1	2.3
May 5	120	1	1	1.6

SOWINGS IN SOIL INOCULATED ON APRIL 4.

Apr. 4	40	26	14	50.00
Apr. 9	22	43	23	75.00
Apr. 24	51	50	24	59.20
May 3	75	11	13	24.24
May 8	91	11	24	27.78
May 23	88	0	1	1.12
June 3	127	0	0	0

The following facts throw some light on the longevity of the spores under different conditions:

(1) Spores were germinated that had been kept dry in the Washington State College herbarium for 12 years.

(2) Heads that had lain in the field from the harvest of 1911 were crushed and mixed with the soil in the fall of 1912 and caused an infection of more than 50 per cent in the following crop.

(3) In the fall of 1913 bunted heads were saved from the harvest of that year and stored under uniformly dry conditions. Other heads from the same plat were left exposed on the ground. In the spring crushed balls from these two lots were used in exactly the same proportion in plats sown to spring wheat. The average of the results from three comparative rod-row tests showed 84.4 per cent of infected plants from indoor-stored heads and 82.4 per cent from outdoor-exposed heads.

(4) In October, 1914, bunt heads from the 1913 harvest were taken from the barn and a quantity of them buried in open ground at a depth of 8 inches. A portion of these heads remained undisturbed until May 1, 1916, when they were dug up and mixed with soil in which 2-rod rows of spring wheat were sown. These rows produced 279 plants, of which 44.29 per cent were infected. The control was bunt free. What was originally about a half-bushel of heads was used in the 2-rod rows; hence, only a very small percentage of the spores needed to be viable in order to produce the above infection. As a matter of fact a microscopic examination of these spores when dug up showed that they were mostly dead.

Saprophytic growth of Tilletia in the Palouse soils after the germination of the spore is limited to 50 days at most and under specially

favorable growth conditions may run its course within 20 days. The exact limit is difficult to determine under field conditions because of the practical impossibility of knowing when the last spores germinated.

PHYSIOLOGIC RESPONSE OF SPORES OF TILLETIA TO TEMPERATURE.

Field experiments to determine the relation of temperature to bunt production, the condensed results of which are shown in Table 5, were made in the spring of 1915. Each sowing consisted of two 1-rod rows each of Pacific Bluestem, Early Wilbur, and Red Chaff wheat. All the seed was thoroughly blackened with spores of *Tilletia tritici*. The soil was well worked and in good tilth. These varieties differ widely in susceptibility, and these differences showed themselves consistently in all seedings. Table 5 shows only the averages for each date. The calculated mean soil temperature is based on observations by means of soil thermometers for the day of seeding and six days following.

TABLE 5.—*Results of an experiment to determine the relation of soil temperature to bunt production at Pullman, Wash., in 1915.*

[The experiment consisted of successive sowings in 1-rod rows of Pacific Bluestem, Early Wilbur, and Red Chaff wheat. The seed was all inoculated before sowing.]

Date sown.	Percentage of bunt-free and bunted plants.			Percentage of bunted heads.	Mean soil temperature (°C.)	Rainfall.
	Bunt free.	Partly bunted.	Wholly bunted.			
Apr. 24	33.49	25.98	40.53	47.44	.....	Apr. 26, 0.71 inch.
Apr. 30	28.16	32.37	39.47	56.02	10.0	
May 7	46.35	31.57	22.08	31.69	13.3	May 8, 9, and 10, 0.90 inch.
May 11	35.80	38.15	26.05	47.87	10.8	
May 15	46.01	27.23	26.76	40.32	13.3	May 14, 0.05 inch.
May 21	98.35	1.00	.65	1.00	21.1	May 17, 18, and 19, 0.41 inch.
May 25	98.42	1.24	.34	.55	18.3	
May 31	99.16	0	.84	.67	24.2	

On April 24 three varieties of winter wheat of medium susceptibility were sown under exactly the same conditions and in ground adjacent to the plats of spring wheat. These failed to head in the summer of 1913, and a portion survived the winter. By the following spring these plants were of a rather unhealthy appearance, but produced some heads with no trace of bunt.

Evidently all the infected plants in this experiment failed to survive the winter. A series of fall sowings was begun on July 28, 1913, in which only Hybrid 143, a very susceptible variety, was used. The seed grain was thoroughly blackened with bunt spores. The plat was on a south slope where the soil, until the opening of the rainy season, was thoroughly dry when the earlier sowings were made. As a consequence, it was necessary to bring the soil to good moisture condition by irrigation three to five days before each sowing. The data on mean temperature in this case cover the time from sowing to the appearance of the first blade and are taken from the records of a soil thermograph located in the plats, with the capsule placed at the seeding depth, 2 inches. Each sowing consisted of 300 grains in a

25-foot row. The yield was from 1,000 to 1,200 heads to the row. Only a count of heads was made. The results are shown in Table 6.

TABLE 6.—*Relation of soil temperature to bunt infection as shown by the percentages of bunted heads of wheat, Hybrid 143, sown at Pullman, Wash., on successive dates in 1913.*

[The mean soil temperature stated is for the period from sowing to the appearance of the first blade.]

Date sown.	Mean soil temperature.	Bunted heads.	Date sown.	Mean soil temperature.	Bunted heads.
	° *C.*	*Per cent.*		° *C.*	*Per cent.*
July 28	25.0	0.08	Sept. 22	10.0	50.00
Aug. 11	18.9	.60	Sept. 30	10.0	86.00
Aug. 20	25.4	.32	Oct. 13	8.1	92.90
Sept. 1	18.3	.19	Oct. 17	8.1	97.30
Sept. 1	18.3	.23	Oct. 25	5.5	91.00
Sept. 10	19.7	2.30	Nov. 7	4.2	48.20
Sept. 15	15.6	3.00	Nov. 11	3.0	55.30

For the sowings in the spring of 1914 a soil thermograph was not available. The preparation of the seed was the same as in the preceding experiment. When each sowing was made in the field a pot was filled with the same soil and sown with the same seed, later to be taken to the greenhouse and placed under a bell jar where moisture conditions could be made to approximate those in the field. As soon as the seedlings had emerged from the coleoptile they were transplanted to the field immediately alongside the field row. These two contemporaneous sowings headed about the same time; that is, the time gained by the quicker germination in the greenhouse was lost by the transplanting. The comparatively high bunt infection in the sowing of March 19 in the greenhouse was evidently because of the relatively low temperature, a condition resulting from absence of artificial heat and deficient sunshine. The results are shown in Table 7.

TABLE 7.—*Relation of soil temperature to bunt infection as shown by the percentage of bunted plants of wheat, Hybrid 143, sown at Pullman, Wash., on successive dates during the period from March 3 to April 1, 1914.*

Date of sowing.	Outdoor plants.		Greenhouse plants.	
	Number.	Infection.	Number.	Infection.
		Per cent.		*Per cent.*
Mar. 3	101	76.2	37	5.4
Mar. 7	99	60.6	32	6.2
Mar. 19	130	56.2	15	46.7
Mar. 28	100	35.0	27	3.7
Apr. 1	78	29.5	.....	.....

Fall sowings of bunt-inoculated seed of Hybrid 143 were begun on August 14. These early sowings were badly damaged by grasshoppers, a fact which possibly may be related to the high percentage of bunt in the first three sowings. This series of sowings was continued in the spring of 1915, using the same wheat, until the

last of March, after which date it was thought necessary to substitute Early Wilbur, a spring wheat of even greater bunt susceptibility than Hybrid 143. The difference between the two in this respect is shown by three parallel sowings on March 22, 26, and April 4 (Table 8).

TABLE 8.—*Relation of soil temperature to bunt infection, as indicated by the percentages of bunted plants of wheat varieties sown on successive dates at Pullman, Wash., during stated periods.*

[The mean temperatures observed are for intervals following sowing as follows: 7 days for the periods August 14 to September 28, 1914, and from April 24 to June 3, 1915; and for 10 days for the periods from October 3 to November 23, 1915.]

Date of sowing.	Number of plants.			Plants infected.	Mean soil temperature
	Bunt free.	Wholly bunted.	Partly bunted.		
HYBRID 143.					
In 1914:				*Per cent.*	*° C.*
August 14	7	1	1	22.2	21.4
August 17	15	0	2	11.8	20.9
August 19	38	8	8	29.6	20.6
August 21	30	1	1	6.3	20.4
August 24	31	0	1	3.1	20.3
August 26	70	4	2	7.9	19.8
August 28	55	2	3	8.3	19.5
August 31	75	0	3	3.8	19.7
September 2	52	3	0	5.5	18.2
September 5	38	8	14	36.7	15.5
September 9	20	42	37	79.8	11.9
September 14	23	36	53	79.5	10.3
September 15	7	67	34	93.5	10.8
September 17	8	54	30	91.3	12.4
September 19	6	70	35	94.6	16.6
September 21	5	60	42	95.3	14.9
September 23	6	67	35	94.4	15.5
September 25	11	101	42	92.9	14.7
September 28	8	82	29	93.3	12.1
October 3	1	96	14	99.1	9.7
October 5	4	120	14	97.1	10.0
October 8	4	103	12	96.6	10.0
October 11	3	104	9	97.4	9.4
October 14	2	142	12	98.7	8.7
October 18	2	75	1	97.4	7.4
October 21	3	66	7	96.1	8.0
October 25	4	57	1	93.5	8.3
October 31	4	156	10	97.6	6.2
November 2	9	94	17	92.5	5.8
November 5	14	130	15	91.2	4.9
November 9	16	112	12	88.6	3.7
November 10	28	97	36	82.6	3.6
November 23[1]	100	13	13	20.6	2.7
In 1915:					
March 3	2	138	39	98.9	
March 8	2	145	33	98.9	
March 13	10	147	28	94.6	[2]
March 22	22	81	36	84.2	
March 26	9	65	23	90.7	
April 4	52	47	20	56.3	
EARLY WILBUR.					
In 1915:					
March 22	0	189	12	100.0	
March 26	3	104	21	97.7	
April 4	20	106	18	86.1	[3]
April 9	7	136	14	95.5	
April 18	40	85	36	75.2	
April 24	55	52	42	63.1	12.3
May 4	63	49	37	57.7	15.4
May 8	25	66	41	81.1	13.3
May 23	33	80	21	75.4	14.3
June 3	136	6	5	7.5	19.3

[1] Did not come up until spring.
[2] From Mar. 3 to Apr. 4, mean between 1.7° and 4.4° C. (Thermograph out of adjustment.)
[3] Temperature record not reliable.

RELATION OF SOIL MOISTURE TO INFECTION.

On April 3, 1915, a mass of dry soil was mixed with 2 per cent of its weight of bunt spores and moistened to saturation by adding water equal to 32 per cent of its dry weight. The mass was then divided and placed in 15 glass vessels with covers and these again placed inside a large moist chamber. With one exception, as long as these soil masses remained in the moist chamber no spore germination was observed. From time to time the vessels were removed from the chamber and allowed to dry slowly. Dates of removal and subsequent appearance of sporidia are shown in Table 9.

TABLE 9.—*Relation of soil moisture to infection, as shown by the appearance of sporidia on soil masses after removal from moist chamber at Pullman, Wash., in 1915.*

Date removed.	Observation.	Date removed.	Observation.
Apr. 9	Apr. 10, few sporidia.	Apr. 27	Apr. 27, few sporidia.
Apr. 16	Apr. 14, sporidia abundant.	Apr. 28	Apr. 28, sporidia abundant.
Do....	Apr. 17, few sporidia.	May 5	No germination.
Apr. 18	Apr. 21, sporidia abundant.		Removed all remaining vessels to open air and allowed them to dry out more or less slowly. No germination or sporidia observed.
Apr. 21	Apr. 17, sporidia abundant, dried more rapidly.		
	Apr. 19, few sporidia, never abundant.		
	Apr. 22, few sporidia, never abundant.		

The results shown in Table 9 indicate that the germination of bunt spores in saturated soil is inhibited and that the spores lose their viability in about 35 days. To obtain direct evidence as to the relation of moisture to infection, the following experiments were undertaken: Sowings of 50 grains each were made in six half-gallon glazed earthenware pots in soil containing a known percentage of moisture. These pots were then hermetically closed by sealing on glass covers and were kept in the greenhouse. Two sets of six pots each were sown in March. When the wheat seedlings were in leaf they were transplanted to open pots, and later to the open field. Table 10 shows the moisture content of the soil at the time of sowing as well as when the pots were opened for transplanting, in terms of dry soil and percentage of infected plants.

TABLE 10.—*Relation of soil moisture to bunt infection as shown by the percentages of bunted plants of wheat sown at Pullman, Wash., in March, 1915.*

Pot number.	Percentage of soil moisture.		Percentage of plants infected.	Pot number.	Percentage of soil moisture.		Percentage of plants infected.
	At seeding.	At transplanting.			At seeding.	At transplanting.	
Experiment A:				Experiment B:			
No. 1	15.8	11.1	27.0	No. 1	17.1	15.0	3.56
No. 2	22.6	17.6	31.0	No. 2	20.0	.....	0
No. 3	26.2	20.5	12.5	No. 3	24.2	23.4	5.55
No. 4	30.0	25.0	2.3	No. 4	27.0	.....	[1]
No. 5	32.6	27.5	0	No. 5	32.0	27.0	0
No. 6	38.8	33.3	0	No. 6	37.0	32.0	[2]

[1] Lost. [2] All plants died.

MORPHOLOGIC RESPONSE TO PATHOLOGIC CONDITIONS.

No general discussion of the morphology or cytology of the two Tilletia species peculiar to wheat will be undertaken in this bulletin. However, some recent observations deserve mention. Harwood (*11*) and Potter and Coons (*18*) called attention to the difference in appearance between *Tilletia laevis* and *T. tritici*. They found that the latter has the property of shortening the culm to a much greater extent than the former.

Edler (*6*) and Appel (*1, 2*) discuss the extreme differences in form between sound and bunted heads in wheat of the *compactum* type. It is a matter of common knowledge that the bunted *compactum* heads are generally much elongated and more slender; in fact, they approach the *vulgare* type. To this rule, however, there are frequent exceptions. The large use made of club wheats in the Pullman experiments, on account of their susceptibility and the fact that in spite of this drawback they are desirable wheats for that section, gave exceptional opportunities for observing their characters in relation to bunt. These are treated to some extent by Heald and Woolman (*13*). The exceptions occur more frequently in spring-sown club wheats than when sown in the fall. Ordinarily the bunted *compactum* head is abnormally elongated some time before it emerges from the boot. An examination at this time shows the stamens yellow and aborted and the ovary green instead of white and of abnormal size. A microscopic examination of their contents shows them to be full of nearly mature spores. In exceptional cases the head on emerging from the boot has an entirely normal appearance in both shape and color, and in due time the stamens are thrust forth normally. In these heads the shape remains normal until near ripening time when they reveal their character only by the spreading of the glumes. The culms supporting this type of head are of normal height or nearly so. Usually there are a few kernels of wheat in the head, and it is in this type that the partially bunted kernels are most likely to occur. The shortening of the culm is much more pronounced in the *compactum* than in the *vulgare* type.

To determine the age and stage of development at which a seedling becomes noninfectible and the extent of infectible area of the plumule, two experiments were conducted. Infested soil which was used in these experiments was prepared in the following manner: A mass of soil was autoclaved, dried, pulverized, and passed through a 10-mesh screen, after which it was mixed with 2 per cent of its weight of bunt spores. Eight or ten days before using, a portion was moistened to the proper degree and at intervals of two or three days other portions were so moistened. All were kept at a suitable temperature for spore germination. When used the portions were all mixed together and new dry spores added. Thus spore material in an infective stage was insured at the time it was used and for at least two weeks subsequently.

In the first experiment wheat was sown in sterilized soil, and at definite stages of growth the plants were transferred to infested soil. The method of sowing employed in the first experiment was as follows: A pot was filled to the proper height and the soil shaken down and smoothly compacted. Sterilized seed of Hybrid 143 was placed on this surface and covered to the required depths with loose

sterilized soil. In changing to infested soil the original soil was readily shaken out down to the seed without disturbing the roots by inverting the pot. These plantings, made on November 6, were later transplanted to infested soil at a depth of 2 inches.

Pots 3, 5, 7, 9, 10, and 11 (see Table 11) were placed out of doors when transplanted and allowed to remain there until November 17. They were then kept in the greenhouse until November 20, when they were transplanted to open ground, after which no further growth took place until spring. Pots 1, 2, 4, 6, 8, and 12 remained continuously in the greenhouse until November 20.

TABLE 11.—*Relation of age and stage of development of seedlings of Hybrid 143 to susceptibility to bunt infection at Pullman, Wash., November, 1915.*

Pot.	Depth of cover.	Date of change to infested soil.	Length of plumule when transplanted.	Condition at the time of transfer.	Plants.		
					Height above soil Nov. 17.	Number harvested.	Infected.
	Inches.		*Inches.*		*Inches.*		*Per ct.*
No. 1	0.25	Nov. 9	0.125 to 0.250	Coleoptile unbroken	2.00 to 4.00	46	21.8
No. 2	.25	Nov. 10	.250 to .500	do	3.00 to 4.00	39	10.3
No. 3	.50	do	.625 to .875	do	.50	57	1.8
No. 4	.50	do	.750 to 1.000	do	3.00 to 4.00	49	4.1
No. 5	.75	Nov. 11	1.125 to 1.375	do	.50	57	1.7
No. 6	.75	do	1.250 to 1.500	do	3.00 to 4.00	21	4.8
No. 7	1.00	do	1.500 to 1.625	do	.25 to .50	37	0
No. 8	1.00	Nov. 12	2.000 to 2.250	In leaf; coleoptile broken.	3.00 to 4.50	19	0
No. 9	1.50	do	2.000 to 2.250	Coleoptile unbroken	.50 to 1.00	31	3.2
No. 10	1.50	Nov. 13	2.250 to 3.000	In leaf	1.25 to 1.50	52	3.9
No. 11	2.00	Nov. 12	2.000 to 2.250	Coleoptile unbroken	.25 to .50	42	0
No. 12	2.00	Nov. 13	3.000 to 3.500	In leaf; coleoptile split at height of 2 inches.	4.00 to 5.00	43	23.3

It is a noteworthy fact that infection seems to have been inhibited to a considerable degree by transferring the plant to conditions of lower temperature. No temperature records were kept; but the nights were frosty, and practically no growth took place in the outdoor pots. The mean temperature could not have been higher than 5° C. Growth conditions in the greenhouse were optimum. The only explanation that can be offered is that the process of bunt infection may involve the work of an enzym the action of which is inhibited by temperatures not sufficiently low to prevent spore germination and growth of the bunt organism as a saprophyte.

It should be noted that, regardless of whether the primary leaf is free from or inclosed by the coleoptile, infection can and does occur. This fact is shown in Table 11.

The second of these experiments was made in the open field during the period from May 10 to 12, thus making possible the uninterrupted growth of the plants. Early Wilbur, the most bunt-susceptible variety of spring wheat known to the writers, was used. The seed was hand-threshed, free from bunt, and treated 90 minutes in a 1 to 240 solution of formaldehyde. In brief, the experiment involved the sowing of wheat at different depths, with a stratum of infested soil prepared as before described at definite levels above the seed. The plats were protected from rainfall and surface drying by boards until the seedlings were in leaf. The field soil was assumed to be

bunt free; in fact, no wheat had been grown in the immediate locality for several years, and other sowings in surrounding ground proved it to be free from bunt. Figures 1, 2, and 3 show the location and thickness of the infested soil strata. The approximate location of the branching node is shown by a composite diagrammatic sketch of the root system of each plant. From these figures and Table 12 it will be seen that the location of the origin of the tillers with

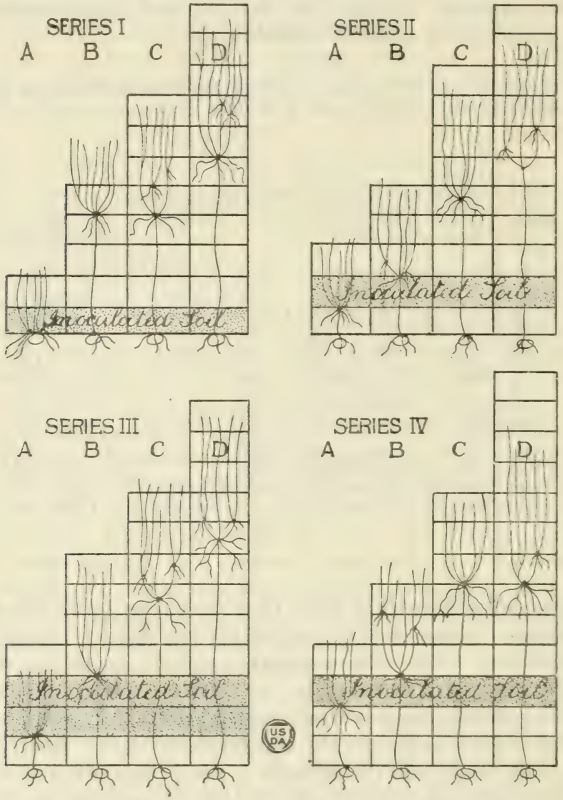

FIG. 1.—Location and thickness of strata of bunt-infested soil in an experiment to determine the possible relation to infection of the distance between seed and stratum of smutted soil. (Vertical scale, each space=one-fourth of an inch.)

reference to the infested stratum is of considerable significance and indicates that direct infection of the tillers does not occur, as little or no infection is shown where they originate below the infested area. The results also show that the percentage of bunt produced is more closely correlated with the total depth of seeding, or the depth of soil above the infested stratum, than it is with the distance between the seed and the infested stratum, for the reason that depth controls the length of the subsurface internode.

TABLE 12.—*Results of the second experiment to determine the age or stage of seedling development at which the wheat seedling becomes noninfectible and the extent of infectible area of the plumule.*

[To be interpreted in connection with the diagrams of Figures 1, 2, and 3.]

Series.	Letter.	Number.		Percentage of plants.			Percentage of bunted heads.	
		Plants.	Heads.	Healthy.	Wholly bunted.	Partly bunted.	In partly bunted plants.	Total.
I	A	20	396	10.0	35.0	55.0	59.4	70.2
	B	9	242	11.1	55.6	33.3	91.9	95.0
	C	8	223	25.0	25.0	50.0	84.3	79.9
	D	8	182	0	50.0	50.0	76.4	88.4
II	A	20	296	85.0	0	15.0	26.2	7.1
	B	13	264	46.1	0	53.9	51.0	28.8
	C	16	295	0	62.5	37.5	75.1	85.4
	D	10	213	10.0	10.0	80.0	76.5	73.2
III	A	22	260	72.7	0	27.3	61.3	17.7
	B	15	230	33.3	13.3	53.3	61.9	50.9
	C	14	205	28.6	42.8	28.6	40.8	50.7
	D	22	269	22.7	50.0	27.3	81.7	70.3
IV	A	28	266	92.9	0	7.1	19.3	2.3
	B	18	220	27.8	22.2	50.0	65.9	55.0
	C	12	172	8.3	41.7	50.0	63.5	70.3
	D	12	177	0	25.0	75.0	63.4	73.3
V	A	25	315	80.0	4.0	16.0	47.0	9.2
	B	17	228	35.3	11.8	52.9	73.9	57.9
	C	18	201	16.7	38.9	44.4	68.5	70.6
	D	5	106	20.0	0	80.0	71.6	62.8
VI	A	23	286	87.0	0	13.0	38.1	9.0
	B	23	264	56.5	17.4	26.1	38.1	28.0
	C	15	234	6.7	26.7	66.7	70.3	74.4
	D	12	202	33.3	33.3	33.3	82.5	64.4
VII	A	17	231	58.8	11.8	29.4	45.3	29.0
	B	18	242	22.2	22.2	55.5	39.1	37.6
	C	10	185	0	30.0	70.0	77.8	82.2
	D	10	202	10.0	60.0	30.0	77.5	85.6
VIII	A	16	246	93.7	0	6.3	80.0	3.3
	B	13	221	69.2	0	30.8	27.5	10.0
	C	15	204	46.7	26.7	26.7	51.4	32.8
	D	14	194	42.8	28.6	28.6	74.0	41.9
IX	A	12	208	66.7	8.3	25.0	7.9	4.3
	B	10	168	80.0	0	20.0	74.2	13.7
	C	16	212	43.7	25.0	31.3	46.8	44.8
X	A	16	207	100	0	0	.....	0
	B	13	208	30.8	0	69.2	57.1	46.2
	C	11	198	27.3	54.5	18.2	55.2	46.0

RELATION OF TEMPERATURE TO THE GERMINATION OF BUNT SPORES AND WHEAT KERNELS.

To determine the importance of temperature as a factor in the germination of bunt spores and wheat, an extended series of cultures was conducted by the junior writer in the laboratory of plant pathology, Bureau of Plant Industry, where access was had to a compartment incubator. One additional culture was carried in a high-temperature incubator maintained at 29.1° C.

The cultures in each case consisted of bunt spores and wheat kernels sown on the surface of finely pulverized moist basaltic soil obtained from Pullman, Wash. These cultures were grown in Petri dishes and were incubated over a total period of 18 days in every case except culture 1 in incubator 1, which was maintained at an

average temperature of 1.4° C. for 25 days. The first attempts made with these cultures failed to yield uniformly satisfactory results, in spite of the fact that every precaution necessary to the preparation of the medium had been observed. By experiment it was found that a perfectly normal spore germination obtained in those cultures over which the Petri dish cover had been lifted and pushed slightly to one side. Cultures incubated at the same temperature but allowed to remain covered germinated indifferently or not at all. It was

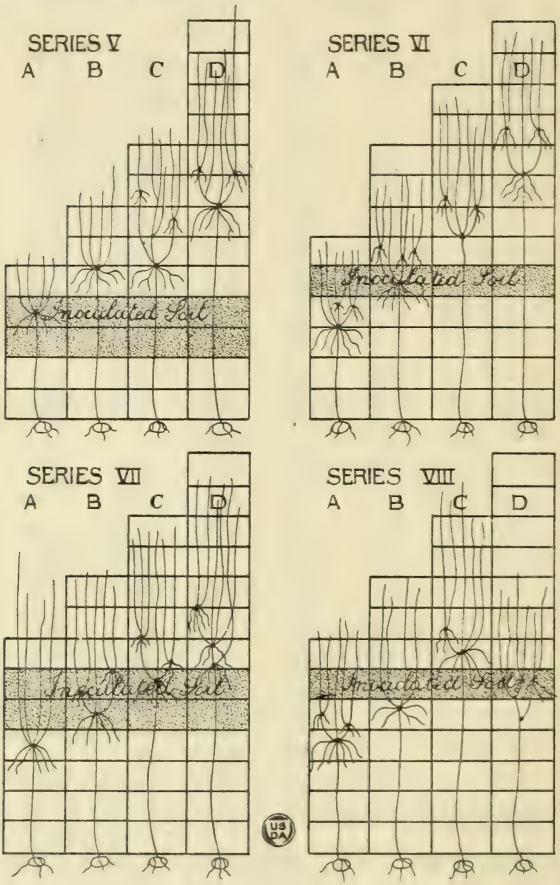

FIG. 2.—Location and thickness of strata of bunt-infested soil in an experiment to determine the possible relation to infection of the distance between seed and stratum of smutted soil. (Vertical scale, each space=one-fourth of an inch.)

also noted that in all cases where germination did obtain in the covered dishes it was always delayed. It was thus demonstrated that available free oxygen is a factor essential to the normal germination of the bunt spore. The same fact has been shown by experiment with water cultures and with various solid media (Brefeld et al.), but experimental proof of the importance of aeration to the wholesale and normal germination of bunt spores and subsequent production of sporidia in or on the soil has not been recorded.

Reference to Table 13 shows that spores maintained at a temperature of 1.4° C., when properly aerated, germinated profusely after a lapse of 24 days, while the germination of wheat, marked by emergence of the plumule, occurred on the tenth day of incubation. Primary conidia were produced in abundance, and the cultures were maintained until the seedlings were 7 millimeters long.

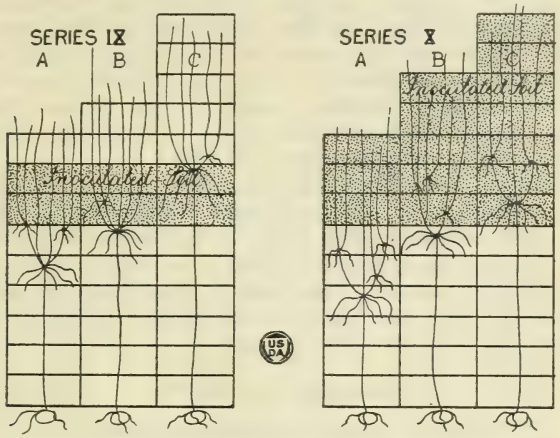

FIG. 3.—Location and thickness of strata of bunt-infested soil in an experiment to determine the possible relation to infection of the distance between seed and stratum of smutted soil. (Vertical scale, each space=one-fourth of an inch.)

That the spores of *Tilletia tritici* are able to retain their viability under the adverse conditions of alternate freezing and thawing was demonstrated by allowing a water decoction of spores in a watch glass to freeze solid every night for more than a fortnight. Before the twentieth day there was profuse germination.

TABLE 13.—*Relation of temperature to germination of bunt spores of Jones Fife wheat, as shown by incubator experiments conducted at intervals during 1913 and 1914.*

Incubator.	Temperature, average for 18 days (°C.).	Spore response.	Wheat kernel response.
No. 1	1.4	First signs of germination on 25th day.	Plumule 1 mm. long on 10th day; 7 mm. long on 25th day.
No. 2	4.9	First signs of germination on 12th day.	Plumules emerging on 4th day.
No. 3	8.6	First signs of germination on 5th day.	Plumules emerging on 2d day.
No. 4	13.4	First signs of germination on 4th day.	Do.
No. 5	19.0	First signs of germination on 2d day.	Plumules emerging at beginning of 2d day.
No. 7	29.1	No response.	Plumules emerging on 1st day.

The optimum temperature for the germination of bunt spores according to results obtained with the compartment incubator lies between 18° and 20° C. Above that point, although there may be a fair degree of germination, it is difficult for the bunt organism to maintain itself against saprophytic molds which thrive at the higher

temperatures. Spores incubated 18 days at 29.1° C. failed to germinate and when afterwards exposed several days to optimum conditions showed no sign of life.

Inoculated wheat seedlings were later removed from the several incubator chambers and transplanted to a field nursery plat. All plants were in first leaf or older when transplanted and came to maturity in the field; but in no case was there any evidence of bunt infection, notwithstanding the fact that during the period of incubation the seedlings were in contact with the parasite in every stage of its saprophytic development. This would seem to afford further support to the tentative position taken by the writers that there is a possible correlation between the degree of probable infection and the relative soundness of the coleoptile tissue.

It is not known how the bunt organism gains access to its host. Culturing the fungus on cellulose agar failed to demonstrate its ability to digest cellulose and there is no definite evidence of its dependence on enzymic agents to prepare the host tissue for invasion. It is not improbable that entry is made by way of moribund coleoptile tissue, or possibly the way may be prepared for it by the action upon the coleoptile of some soil organism.

CONTROL OF BUNT.

NURSERY STUDIES IN SEED TREATMENT.

Experiments in seed treatment for the control of bunt were begun at Pullman, Wash., in the spring of 1914. Bunt spores were worked into the soil on April 19, and sowings in plats of three 1-rod rows each were made on April 24, with the results shown in the first part of Table 14.

Seed treated as shown in the second part of Table 14, dried, and then bunted, was sown on October 20, 1914, in soil subject to bunt showers. The results show the combined effect of seed-borne spores and soil infestation.

TABLE 14.—*Relation of soil infestation to infection of wheat by bunt at Pullman, Wash., in April and October, 1914.*

SOWINGS IN SOIL INOCULATED ON APRIL 19 AND IN CLEAN SOIL.

Plat.	Seed treatment.	Plants infected.
		Per cent.
No. 1	Seed treated 30 minutes in a solution of 1 pound of copper sulphate and 1 pound of salt to 2½ gallons of water, sown in infested soil	16.3
No. 2	Seed treated as in plat 1, then bunted, and sown in clean soil	4.1
No. 3	Seed treated 2 hours in a 1 to 240 solution of formaldehyde, sown in infested soil	50.1
No. 4	Seed treated as in plat 3, then bunted, and sown in clean soil	22.9

SOWINGS ON OCTOBER 20 IN SOIL SUBJECT TO BUNT SHOWERS.

No. 1	Seed treated 30 minutes in a solution of 1 pound copper sulphate and 1 pound salt to 2½ gallons water	40.3
No. 2	Same as plat 1; washed in water after treatment	59.7
No. 3	Seed treated 30 minutes in a solution of 1 pound copper sulphate in 2½ gallons of water	40.2
No. 4	Same as plat 3; washed in water after treatment	55.7
No. 5	Seed treated 90 minutes in a 1 to 240 solution of formaldehyde	82.5
No. 6	Seed treated 10 minutes in water at 57° C	79.2

In order to determine the possible virtue of any fungicide or fungicides as immunizing agents against infection from spores present in the soil, an experiment involving the use of several such preparations was conducted. The results are given in Table 15.

TABLE 15.—*Relative value of various treatments as immunizing agents in infested soil, at Pullman, Wash., in 1914.*

[Soil inoculated on November 1, seed sown on November 3, 1914.]

Plat.	Seed treatment.	Highly infested soil.		Lightly infested soil.	
		Plants.	Bunted heads.	Plants.	Bunted heads.
			Per cent.		*Per cent.*
No. 1	Immersed for 40 minutes in a solution of 1 part commercial lime-sulphur to 20 parts water	48	61.05	39	9.27
No. 2	Immersed for one-half minute in commercial lime-sulphur, full strength: dried	178	26.50	131	2.50
No. 3	Copper sulphate: 1 pound to 1 gallon water; grain sprinkled and dried	92	11.46	80	0
No. 4	Immersed for 20 minutes in 1 pound copper sulphate and 1 pound salt to 5 gallons water	178	37.24	114	1.93
No. 5	Immersed for 20 minutes in 1 pound copper sulphate to 5 gallons water	157	45.15	132	3.82
No. 6	Grain rolled dry in Bordeaux powder	130	37.11	110	5.62
No. 7	Grain rolled damp in Bordeaux powder	104	39.34	133	10.19
No. 8	Corbin's Protector	31	4.24	17	12.50
No. 9	Formaldehyde: 160 c. c. of a 1 to 240 solution: sprinkled and dried	382	71.09	324	26.91
No. 10	Copper sulphate: 160 c. c. of a solution 1 pound to 5 gallons water: sprinkled in open drill before sowing	325	60.82	334	21.04
No. 11	Lime worked into the soil	144	40.07	339	24.55
No. 12	Immersed for 30 minutes in a 1 to 240 solution of formaldehyde (control)	339	55.15	240	9.59

Table 16 shows the results of sowing variously treated seed in summer fallow. There was no artificial infestation of either the soil or the seed; therefore, the bunt in the resulting crop was due to infection arising from wind-disseminated spores. The plats were in duplicate and were sown in early October. Check plats sown in soil from which any wind-disseminated spores had been removed by surface burning were all bunt free.

TABLE 16.—*Relative value of different methods of seed treatment for prevention of bunt in wheat sown on summer-fallowed land at Pullman, Wash., October, 1914.*

Seed treatment.	Plat.	Number of plants.			Plants infected.	
		Bunt free.	Partly bunted.	Wholly bunted.		
					Per cent.	
Formaldehyde solution, 1 to 240; 90-minute soak	A	31	5	19	43.6	36.4
	B	34	5	9	29.2	
Copper sulphate, 1 pound to 1 gallon water: sprinkled on seed.	A	71	4	8	14.5	13.8
	B	40	2	4	13.0	
Copper sulphate + common salt, 1 pound each to 1 gallon water; sprinkled on seed.	A	68	6	13	21.8	14.2
	B	43	1	2	6.5	
Copper sulphate, 1 pound to 5 gallons water; 10-minute soak.	A	52	12	16	35.0	27.5
	B	60	6	9	20.0	
Copper sulphate + common salt, 1 pound each to 5 gallons water; 10-minute soak.	A	45	5	12	27.4	24.6
	B	43	3	9	21.8	

Infection from infested soil can be considerably reduced by incrusting the seed with a soluble fungicide and sowing no deeper than is required by soil-moisture conditions. The degree of such protection may be profoundly affected by the temperature and moisture conditions of the soil, the optimum conditions consisting in a temperature of approximately 18° C. (64° F.), soil in good tilth, and low atmospheric humidity. Such conditions would promote prompt germination of the grain and an upward flow of the dissolving toxin by capillary action; while the most unfavorable conditions would result from a combination of soil temperature sufficiently low to cause slow germination of the seed and a wet, poorly aerated soil, which would cause the toxins to percolate downward.

In this connection, threshing damage to the seed coat of the wheat, which increases its susceptibility to injury from copper-sulphate treatment, is of importance. Experiments by Nobbe (*17*), Grassman (*10*), Falke (*7*), and Tubeuf (*22*) established the relation of seed-coat injury to loss of viability after treatment with copper sulphate. Falke (*8*) found a great difference in the germinative power of wheat of the 1903 and 1904 harvests after treatment with $CuSO_4$. Even after sorting out all visibly injured grains a considerable difference was manifest. The crop season of 1904 was an exceptionally dry one, and Falke believed this condition to cause the seed coat to be more permeable and more easily injured.

Volkart (*24*) found hand-threshed wheat immune from injury by copper sulphate when immersed 14 hours in a 0.5 per cent solution, while machine-threshed seed treated in the same manner was almost entirely killed. He also found that a four-hour treatment in a 0.1 per cent solution of formaldehyde killed a large part of the machine-threshed seed, while the hand-threshed seed was uninjured except that its germination was slightly delayed and the seedling growth retarded.

Brown (*5*) found the testa of wheat, barley, and oats to contain a semipermeable or selective membrane; this, while admitting water freely, excluded sulphuric acid and certain salts, among which were copper sulphate and silver nitrate. Schroeder (*19*) confirmed Brown and found further that the membrane was permeable to an aqueous solution of mercuric chlorid and to chloroform. The work of Shull (*20*) in 1913, directed principally toward an explanation of the phenomena along physical and physiological lines, developed no further facts related to the immediate problem of seed treatment.

In the Northwest the injury to wheat from threshing was found to be excessive. The reasons for this are (1) that it is almost always threshed very dry, the atmospheric humidity in these regions being extremely low during July, August, and early September; and (2) threshing machines are run at very high speed. It is not unusual to find 10 per cent of the kernels of a lot of wheat split in halves. Field observations and laboratory experiments showed that an immense amount of seed was being lost through treatment with copper sulphate in consequence of this threshing injury. An investigation of this problem was reported by Woolman (*25*). These studies showed that the point where copper-sulphate solution is the most deadly is the hilar membrane covering the extremely susceptible radicle, where breaks in the testa of the seed are most likely to occur. A

further and more exhaustive study of the subject has been reported by Hurd (*15*). Ocular evidence of the different responses of hand-threshed and machine-threshed wheat to treatment by copper sulphate and formaldehyde is presented in Plates I to V.

The following facts are emphasized by these plates:

(1) The desirability of instituting some method of threshing seed grain that will eliminate this loss, which certainly amounts to half of the seed sown where the copper-sulphate treatment is necessary.

(2) In the case of machine-threshed grain the injury to germination by treatment with copper sulphate is almost as great from a five-minute bath as from one lasting an hour.

(3) The injury by treatment with formaldehyde, while not nearly so great as that resulting from copper sulphate for a short period of exposure, increases continuously as the time of exposure is prolonged.

(4) A comparison of the photographs of the pot cultures taken 28 and 40 days after planting shows a higher power of recovery in plants grown from seed injured by copper sulphate than is the case with plants from seed injured by formaldehyde.

If wheat must be sown in infested soil, the only control measures appear to be those indicated above, together with the introduction and adoption of the least bunt-liable varieties. There are, however, several possible means of avoiding the necessity of using such infested soil.

The most important and practical of these are:

(1) Collection and destruction of the spores at the threshing machine.

(2) Sowing winter wheat before threshing begins; this is practicable in the less arid regions when harvest is comparatively late, if the summer fallow has been thoroughly cultivated and varieties of pronounced winter habit are used. Fortunately this method is applicable in that part of the country where the greatest bunt losses have occurred.

(3) Replowing the summer fallow before seeding, so as to bury the spores below the seed bed.

(4) Delaying seeding until sufficient time has elapsed after fall rains begin for the spores to germinate and die.

(5) Spring seeding.

(6) It may be possible to construct a drill attachment which would remove the infested soil from the immediate vicinity of the seed, where such soil is confined to the surface, as would be the case when no tillage has occurred after the smut shower.

RELATION OF DEPTH OF SEEDING TO BUNT PRODUCTION.

Whether or not the depth of seeding bears any relation to the production of bunt in the resulting crop seems not to have been investigated.

Inasmuch as the plumule is susceptible to infection at any point below the surface of the soil, it would logically follow that where infective material was distributed throughout the seed bed, deep sowing would increase the liability to infection. However, there would remain the question as to what extent the harvest is affected by the location of the point of entrance of the fungus into the plumule.

Experiments to determine the effect of the depth of seeding indicate that, in general, wheat plants possess the power to overcome infection, and that this power increases with the distance from the seed to the point of entrance of the fungus. This is shown by the proportion of partly bunted plants to those which are wholly bunted. (Table 17.)

TABLE 17.—*Results of experiments to determine the effect of depth of seeding on bunt infection at Pullman, Wash., in 1914.*

INOCULATED UNTREATED SEED OF EARLY WILBUR WHEAT SOWN IN BUNT-FREE SOIL.

Date of seeding.	Depth sown (inches).	Total plants.	Percentage of plants.		Percentage of bunted heads.	
			Partly bunted.	Wholly bunted.	In all plants.	In partly bunted plants.
Mar. 17	0.5	181	31.7	19.3	34 9	53.9
	1.0	168	16.0	76.2	88.8	70.0
	1.5	190	4.2	95.3	98.5	74.6
	2.0	181	1.6	97.3	98.4	61.6
	2.5	189	0	100.0	100.0	.....
	3.0	185	1.1	98.4	99.7	77.7

INOCULATED UNTREATED SEED OF HYBRID 143 SOWN IN BUNT-FREE SOIL.

Mar. 17	0.5	30	0.0	3.3	(1)	(1)
	1.0	45	55.5	9.1	(1)	(1)
	1.5	77	18.2	36.4	(1)	(1)
	2.0	78	38.5	39.7	66.1	65.8
	2.5	129	19.4	68.2	79.3	67.3
	3.0	196	19.4	71.4	83.9	68.3

CLEAN TREATED SEED OF EARLY WILBUR WHEAT SOWN IN ARTIFICIALLY INOCULATED SOIL.

Mar. 19	0.5	104	43.3	22.1	47.8	58.0
	1.0	120	29.2	52.5	66.4	64.1
	1.5	79	34.2	54.4	75.2	65.1
	2.0	58	24.1	63.8	83.8	70.1
	2.5	62	16.1	80.6	92.1	76.0
	3.0	49	20.4	75.5	91.2	71.2

CLEAN TREATED SEED OF HYBRID 143 SOWN IN ARTIFICIALLY INOCULATED SOIL.

Mar. 19	0.5	149	10.7	10.7	16.8	47.4
	1.0	161	36.0	12.4	35.0	57.2
	1.5	94	42.5	16.0	39.8	58.4
	2.0	96	40.6	33.3	60.0	65.5
	2.5	69	16.0	68.1	74.8	69.6
	3.0	59	8.5	76.3	80.9	60.8

CLEAN TREATED SEED OF HYBRID 143 SOWN IN BUNT-INFESTED SOIL.[2]

Sept. 1	0.5	216	3.7	0	0.35	7.0
	1.5	229	12.23	0	2.03	14.85
	3.0	100	21.00	0	2.22	10.06
Oct. 4	.5	220	37.72	21.36	49.89	63.55
	1.5	229	44.11	32.31	61.65	67.56
	3.0	215	21.86	65.11	81.64	75.07

SMUTTY SEED OF HYBRID 143 SOWN IN SOIL NOT ARTIFICIALLY INOCULATED.[3]

Sept. 1	0.5	277	3.61	0.38	0.82	19.60
	1.5	258	3.50	1.54	1.93	33.63
	3.0	105	4.76	2.86	2.78	18.75
Oct. 4	.5	238	19.75	8.40	11.88	46.60
	1.5	296	25.34	70.61	92.36	81.58
	3.0	290	6.21	92.06	96.85	79.08

[1] Not counted. The 0.5, 1, and 1.5 inch sowings were badly smothered by the more rapidly growing Early Wilbur, the two varieties being sown in alternate rows. Many of the Hybrid 143 plants produced but one head.

[2] Soil thoroughly inoculated with bunt spores Sept. 1.

[3] This soil was undoubtedly more or less contaminated with wind-borne spores.

RELATION OF RATE OF SEEDING TO BUNT PRODUCTION.

The phase of the problem covering the relation of the rate of seeding to bunt production has received little attention by other investigators. Tubeuf (*23*) reports observations on the percentage of bunt found in the plants growing on the edge of plats in comparison with those nearer the center. In three varieties a slightly higher percentage of bunted plants and heads occurred on the outside of the plats, the greatest difference being 4.8 per cent of total heads. In Bestehorn's Ueberfluss, a variety of low-bunt liability, the outside plants gave 1.1 per cent bunt and the inside 3 per cent. The observations and experiments of the writers on this phase are meager and not very conclusive. However, the results of the following experiment seem to harmonize in part with those of Tubeuf. Attempts to repeat this experiment failed because of disastrous winter-killing.

Hybrid 143 and Turkey (Washington 326), the varieties used in this experiment, were uniformly smutted by shaking 100 grams of seed with 4 grams of spores. The rates of seeding varied from 0.5 inch apart in 6-inch rows to 12 inches apart in 12-inch rows. Three 1-rod rows for each spacing were seeded on October 28, 1915. It will be seen from Table 18 that in Hybrid 143 the percentage of bunted heads is not as definitely related to the density of stand, as it is in the resistant Turkey where the rate of seeding seems to have a more pronounced effect. As it is not conceivable that plants growing 12 inches apart could be less subject to infection than plants from the same seed lot sown one-half to 2 inches apart on the same day in the same soil, it seems evident that the plants in this variety have, to some extent, the power of outgrowing the invading fungus and that this power is influenced by growth conditions.

TABLE 18.—*Results of an experiment to determine the relation of rate of seeding of wheat varieties to bunt production at Pullman, Wash., in October, 1915.*

Variety and rate of seeding.	Percentage of plants.		Percentage of bunted heads.		Average density per rod row.	
	Bunted.	Partly bunted.	In all plants.	In partly bunted plants.	Plants.	Heads.
Hybrid 143:						
6 by 0.5 inch	54.66	5.04	60.35	96.70	198.5	635.5
6 by 1 inch	60.14	5.59	63.89	68.00	142	744
6 by 3 inches	38.32	21.56	54.50	70.73	56	588
6 by 6 inches	42.67	20.00	55.36	68.90	25	308
12 by 0.5 inch	48.27	11.96	58.08	59.13	231	1,127
12 by 1 inch	60.70	12.34	65.27	62.40	148	1,044
12 by 2 inches	57.54	16.89	74.52	80.61	73	964
12 by 3 inches	46.31	23.85	69.67	72.76	50	769
12 by 6 inches	35.71	37.14	67.09	78.51	23	622
12 by 12 inches	28.57	42.86	61.00	72.53	12	341
Turkey:						
6 by 0.5 inch	12.29	29.24	17.88	34.20	193	811
6 by 1 inch	7.75	37.47	19.02	34.38	129	724
6 by 3 inches	0	32.35	5.64	15.58	45	538
6 by 6 inches	0	24.73	2.03	22.68	30	361
12 by 1 inch	15.64	49.02	30.40	39.90	205	989
12 by 2 inches	4.57	51.08	18.68	31.98	124	867
12 by 3 inches	0	32.52	5.20	17.03	54	686
12 by 6 inches	0	30.34	3.39	12.06	30	609
12 by 12 inches	0	28.26	3.19	10.37	15	470

TABLE 19.—*Results of an experiment to determine the possible relation of date of seeding to bunt infection of resistant and susceptible varieties of wheat sown at Pullman, Wash., on successive dates during the interval from April 23 to May 22, 1915.*

Variety.	Production of bunted plants and heads (per cent).														
	Sown Apr. 23.			Sown May 5.			Sown May 8.			Sown May 15.			Sown May 22.		
	Plants.		Bunted heads.	Plants.		Bunted heads.	Plants.		Bunted heads.	Plants.		Bunted heads.	Plants.		Bunted heads.
	Partly bunted.	Wholly bunted.		Partly bunted.	Wholly bunted.		Partly bunted.	Wholly bunted.		Partly bunted.	Wholly bunted.		Partly bunted.	Wholly bunted.	
Hybrid 143	7.6	16.6	19.2	9.4	8.2	13.4	9.5	12.9	16.0	17.4	36.1	45.0	0.8	10.1	7.0
Red Chaff	22.7	29.2	45.9	24.9	12.2	29.5	22.9	16.0	23.7	16.4	57.1	69.7	26.8	1.6	.....
Early Wilbur	15.8	52.8	57.9	22.4	27.1	42.4	35.6	20.1	39.5	35.5	45.7	66.6	25.0	25.6	35.4
Minnesota 163	10.3	7.4	11.0	6.7	1.9	4.0	3.9	0	2.4	14.5	4.1	7.6	4.0	.7	1.5
Minnesota 169	6.3	2.7	3.9	3.2	.7	2.5	5.4	.6	2.0	29.1	4.3	12.6	6.0	0	.7
Minnesota 188	6.8	5.2	9.4	8.1	2.6	5.4	8.3	1.1	5.0	21.3	4.1	8.5	7.8	2.9	3.2
Florence	2.1	.6	1.9	2.7	.8	.7	0	0	0	1.5	.5	.8	1.1	.5	.3
Scotch Fife	4.8	1.8	3.4	3.9	3.9	.....	13.0	0	.....	11.1	1.1	.....	6.0	.6	.....
Minnesota Bluestem	9.5	2.4	5.6	7.7	2.0	.....	11.9	.1	.....	25.1	0	.....	11.1	1.2	.....

TABLE 20.—*Relative susceptibility to bunt of 26 varieties of spring-sown wheat, emmer, spelt, and rye and 22 varieties of winter wheat sown at Pullman, Wash., in 1915.*

SPRING WHEATS SOWN IN PLATS OF FOUR 1-ROD ROWS ON APRIL 13, 1915.

[Seed of varieties marked with a star (*) was Washington grown; seed of those marked with a dagger (†) was Minnesota grown.]

Variety.	Production of bunted plants and heads (per cent).				Variety.	Production of bunted plants and heads (per cent).			
	Plants.			Bunted heads.		Plants.			Bunted heads.
	Bunt free.	Wholly bunted.	Partly bunted.			Bunt free.	Wholly bunted.	Partly bunted.	
Early Wilbur	5.94	35.64	58.42	84.01	Alaska 552	84.75	0	15.25	4.97
Jenkin Club 526	13.04	32.61	54.35	69.76	Red Allen 265	9.52	41.67	48.81	77.95
Little Club 500	6.25	57.44	36.31	84.26	Florence	71.74	.87	27.39	8.02
Red Fife 268	14.52	30.64	54.84	70.69	Bluestem	10.64	36.17	53.19	77.63
Red Fife 613	35.09	0	64.91	22.57	Sonora 279	4.09	70.18	25.73	88.34
Minnesota 163*	14.55	21.82	63.63	44.81	Early Baart 618	7.14	26.19	66.67	71.23
Minnesota 163†	25.37	14.92	59.71	40.25	Chul × Bluestem	3.66	59.76	36.58	85.69
Minnesota 188†	19.15	19.15	61.70	49.25	Talenco 615 [2]	5.43	50.00	44.57	76.88
Minnesota 188*	21.43	17.86	60.71	51.67	Columbian	13.98	48.82	37.29	74.97
Marquis 576 [1]	16.22	1.80	81.98	47.78	Kubanka	56.30	6.72	36.98	29.39
Brown's Glory 550	9.62	49.04	41.34	81.44	Emmer	12.90	33.87	53.23	64.96
Hybrid 143	9.75	51.22	39.03	80.03	Spelt	21.80	7.69	70.51	36.32
Noe 617	58.24	10.99	30.77	18.72	Polish	86.84	0	13.16	2.87
Dicklow 630	1.49	70.15	28.36	91.71	Rye	100.00	0	0	0

WINTER WHEATS SOWN IN PLATS OF SIX 1-ROD ROWS ON OCTOBER 13, 1915.

Turkey	30.00	3.33	66.67	20.30	Hybrid 128	6.14	79.86	14.00	89.39
Florence	37.88	2.81	59.31	18.32	Little Club	6.42	91.12	2.46	92.29
Winter Fife	.87	92.99	6.14	94.84	Quadruplet	10.13	72.21	17.66	89.37
Fortyfold	13.71	35.08	51.21	75.65	Red Russian	15.62	47.92	36.46	68.71
Berberisco	4.65	75.58	19.77	92.18	Turkey × Winter Fife (Washington 587)	5.84	79.22	14.94	89.49
Hybrid 143	4.71	77.65	17.64	95.40					
Coppei	9.49	64.96	25.55	83.45					
Alaska	46.75	12.99	40.26	31.65	Winter Fife × Turkey × Winter Fife × Little Club	3.60	61.26	35.14	85.49
Triplet	12.81	55.03	32.16	75.48					
Turkey × Little Club × Turkey	4.85	48.89	46.26	85.11	Hybrid 123	4.78	84.93	10.29	90.57
Red Russian × Washington 329	15.05	46.90	38.05	76.63	Hybrid 60	2.46	90.98	6.56	94.13
Winter Bluestem × Turkey × Bluestem	5.73	70.06	24.21	84.24	Triplet's Sister	3.52	64.08	32.40	90.18
					Salzer's Marvel	58.03	12.29	29.68	69.63

[1] In Marquis, only 13.29 per cent of the heads were entirely bunted, and 34.49 per cent of the heads contained both wheat and bunt.

[2] In Talenco, 10 per cent were partly bunted heads.

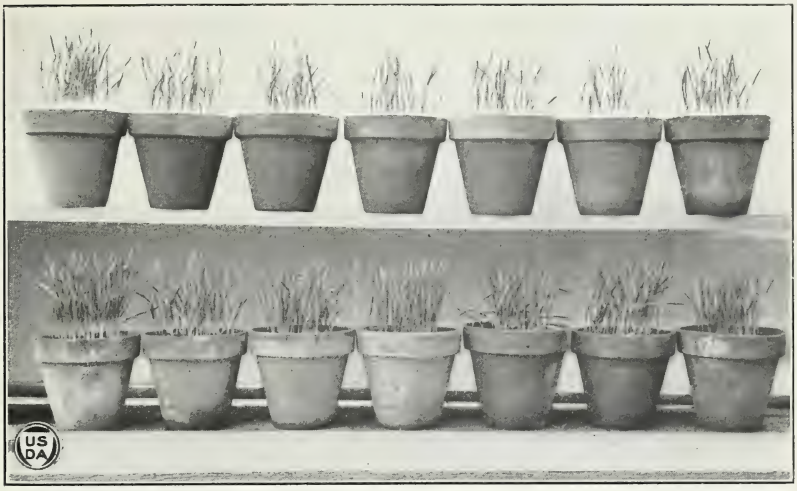

FIG. 1.—PLANTS FROM SEED SOWN MARCH 15, PHOTOGRAPHED MARCH 25.

The upper row consists of plants grown from machine-threshed seed. The lower row represents plants grown from hand-threshed seed. The pots from left to right are: 1, Untreated check; 2, seed immersed 15 minutes; 3, 30 minutes; 4, 1 hour; 5, 2 hours; 6, 3 hours; 7, 5 hours. Note difference in stand and vigor.

FIG. 2.—THE SAME CULTURES PHOTOGRAPHED 13 DAYS LATER.

The effect of the formaldehyde on the vigor of the plants grown from machine-threshed seed is still apparent, though there is evident recovery as growth progresses.

WHEAT PLANTS GROWN FROM SEED TREATED WITH A 1 TO 320 SOLUTION OF FORMALDEHYDE.

FIG. 1.—PLANTS FROM SEED SOWN MARCH 15, PHOTOGRAPHED MARCH 25.

The upper row consists of plants grown from machine-threshed seed; the lower, from hand-threshed seed. The pots from left to right are: 1, Untreated check; 2, seed immersed 5 minutes; 3, 10 minutes; 4, 30 minutes; 5, 1 hour; 6, 5 hours; 7, 10 hours. Note the difference in stand and vigor.

FIG. 2.—THE SAME CULTURES PHOTOGRAPHED 13 DAYS LATER.

The effect of the copper sulphate on stand and vigor is even more pronounced than that following the use of formaldehyde.

WHEAT PLANTS GROWN FROM SEED TREATED WITH A SOLUTION CONSISTING OF 1 POUND OF COPPER SULPHATE TO 5 GALLONS OF WATER.

FIG. 1.—SEEDS IMMERSED 30 MINUTES IN A 1 TO 320 SOLUTION.

The lot of seed at the left was hand threshed; that on the right, machine threshed.

FIG. 2.—SEEDS IMMERSED FIVE HOURS IN A 1 TO 320 SOLUTION.

The lot of seed at the left was hand threshed; that on the right, machine threshed.

EFFECT OF FORMALDEHYDE ON THE GERMINATION OF HAND-THRESHED AND MACHINE-THRESHED WHEAT KERNELS.

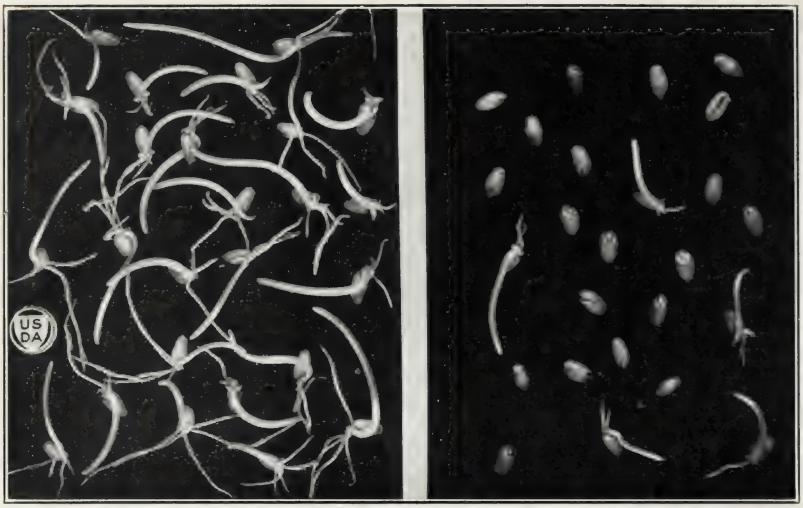

FIG. 1.—SEEDS IMMERSED FIVE MINUTES IN A 1 TO 5 SOLUTION.

The lot of seed at the left was hand threshed and germinated 100 per cent; that at the right was machine threshed and germinated but 20 per cent.

FIG. 2.—SEEDS IMMERSED ONE HOUR IN A 1 TO 5 SOLUTION.

The lot of seed at the left was hand threshed. It germinated 100 per cent, but the longer immersion in the fungicide affected the vigor more seriously than in the case of seed immersed only five minutes. The seed at the right was machine threshed.

EFFECT OF COPPER SULPHATE ON THE GERMINATION OF HAND-THRESHED AND MACHINE-THRESHED WHEAT KERNELS.

FIG. 1.—A CULTURE OF WHEAT AND BUNT ON STERILIZED SOIL.

The smut spores and wheat were sown under conditions as nearly aseptic as possible The growth of the fungus was greatly facilitated by allowing free air to enter by lifting the cover of the Petri dish at one side. The culture was incubated for eight days at an average temperature of 12° C.

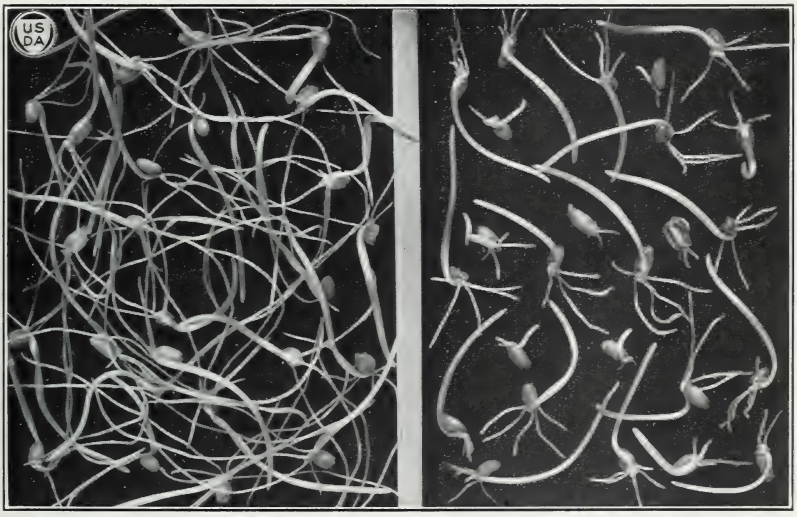

FIG. 2.—EFFECT OF MECHANICAL INJURY OF THE SEED COAT AND EMBRYO ON THE GERMINATION OF UNTREATED WHEAT KERNELS.

The lot on the right represents hand-threshed grain; that on the left shows machine-threshed grain Both lots were germinated in a moist chamber under identical conditions.

BREEDING AND SELECTION STUDIES OF VARIETAL RESISTANCE TO BUNT.

The first observations at Pullman, Wash., on the differences in varietal resistance were made in breeding and selection studies in the spring of 1913. Sowings of Early Wilbur, Red Chaff, and Pacific Bluestem were made on seven different dates. These range from high to medium susceptibility in the order named. Throughout this series, as well as in other years when they happened to be used for various experiments, their relative susceptibility remained the same. The results are shown in Tables 19 and 20.

In Table 21 the proportion of bunted heads in such plants as contain both wheat heads and heads of bunt is given. In those varieties which show the lowest percentage of bunted heads there is a relatively low percentage of such heads in partly infected plants.

TABLE 21.—*Results of an experiment to determine relative varietal susceptibility of wheat to bunt in a plat sown at Pullman, Wash., October 14, 1916.*

Variety.	Production of bunted plants and heads (per cent).				Variety.	Production of bunted plants and heads (per cent).			
	Plants.			Bunted heads.		Plants.			Bunted heads.
	Bunt free.	Wholly bunted.	Partly bunted.			Bunt free.	Wholly bunted.	Partly bunted.	
Red Russian	55.3	0	44.7	18.7	Salzer's Marvel	37.9	15.5	46.6	34.8
Fortyfold	47.7	7.1	45.2	33.7	Florence	72.3	1.3	26.4	6.3
Turkey [1]	73.3	1.3	25.4	9.3	Hybrid 153	27.1	65.6	7.3	61.2
Winter Fife	38.1	38.1	23.8	53.3	Triplet	11.0	63.0	26.0	77.3
Hybrid 60	39.2	48.0	12.8	52.8	White Track	55.6	16.6	27.8	34.8
Hybrid 128	23.5	55.4	21.1	66.1	Winter Bluestem	21.1	45.8	33.1	64.0
Hybrid 123	20.3	58.5	21.2	67.1	Coppei	25.6	34.4	40.0	58.9
Hybrid 143	14.4	72.0	13.6	84.3	Washington 626	15.4	42.3	42.3	65.2
Little Club	30.0	60.0	10.0	61.3					

[1] The 58 bunted Turkey (Washington No. 326) plants produced a total of 633 heads, 575 of which were bunt free, 37 partly bunted, and 21 wholly bunted.

It seems that no variety yet tested is able to resist the entrance of the bunt fungus into the seedling when temperature and moisture conditions are favorable and when the infective stage of the fungus synchronizes with the infectible stage of the wheat. Certain varieties, however, are able in varying degrees to produce wheat in spite of such infection. (See Turkey and Florence, Table 21.) This is shown by the investigations of the writers as well as by those of other workers.

Such characters or factors might conceivably fall into two classes: (1) Those that tend to produce such a rapid development of the plant or certain parts of it that the fungus is simply outgrown or left behind in all or part of the culms of a plant and (2) morphological, physiological, or chemical characters that tend to overcome, suppress, or inhibit the growth and distribution of the fungus within the host. The evidence strongly favors the second set of factors, for if the faculty to produce wheat in spite of infection depended on the ability of the plant to grow away from the fungus merely by rapid development comparative freedom from bunt would appear to be a characteristic of long-strawed varieties. This is not the case, however. For example, the susceptible Winter Fife is among the varieties having the longest straw, while the resistant Florence is comparatively short. Again, a relation between comparative freedom from bunt and rapid growth

and earliness might be expected, but this is not always the case. An example of this is to be seen in Early Wilbur, which will produce the highest percentage of bunt under test conditions of any variety known to the writers. Hybrid 143, which may be used either as a winter or spring wheat, has shown in repeated parallel tests that it is less liable to bunt than Early Wilbur. Yet the latter matures several days ahead of Hybrid 143, and when sown in alternate rows 12 inches apart Early Wilbur will frequently grow so much more rapidly in its early stages that Hybrid 143 will be almost smothered out.

Another fact that seems to support the theory of factors that militate against the distribution of the fungus within the host, independent of rapidity of growth, is to be seen in the comparatively large numbers of partly bunted heads. Whether these factors are chemical, physical, or morphologic is unknown. The fact that the partly bunted heads in Turkey and most other varieties are bunted on one side seems to suggest that there is something in the structure of the culm that partially prevents the mycelium from crossing from one side to the other. Whatever these characters may be, there is little doubt that they are quantitatively transmissible in crosses. The results obtained by Gaines (*9*) from studies carried on contemporaneously with those herein reported appear to establish this fact.

TABLE 22.—*Results of experiments to determine the relative vegetative vigor of four varieties of wheat conducted at Pullman, Wash., in 1915.*

Time from sowing.	Experiment No. 1.		Experiment No. 2.	
	Turkey.	Jones Winter Fife.	Turkey.	Jones Winter Fife.
6 days	No emergence	5 plants; 3 first leaves.	No emergence	Emerging; 3 first leaves ½ to 3.4 inches long.
7 days	6 first leaves ¼ to 1 inch long.	6 first leaves 1 to 2 inches long.	3 first leaves ¼ to ½ inch long.	3 first leaves 1 to 2 inches long.
8 days	7 first leaves 1 to 1½ inches long.	6 first leaves 2½ to 3½ inches long.	6 first leaves ½ to 2 inches long.	2 second leaves in sight.
9 days	7 first leaves 2 to 4 inches long; second leaves not in sight.	12 plants; 6 with second leaves in sight.	11 plants; 3 second leaves ½ to 1 inch long.	10 plants; 3 second leaves ½ to 1 inch long.
12 days	Second leaves 2 to 2½ inches long.	Second leaves 5 inches long.	Second leaves 2½ to 4 inches long.	Second leaf 1 to 2 inches long.
15 days	Third leaves 0 to 1 inch long.	Third leaves ½ to 1½ inches long.	Third leaves ½ to 1 inch long.	Third leaves 1 to 2 inches long.
Time from sowing.	Florence.	Chul × Bluestem.	Florence.	Chul × Bluestem.
5 days	6 plants emerged; no leaves.	2 plants emerged; no leaves.	No emergence	6 plants emerged; no leaves.
6 days	9 plants with first leaf ½ to 2 inches in length.	8 plants; 6 first leaves emerging from coleoptile.	2 plants, 1 first leaf in sight.	9 plants; first leaves ½ to 1½ inches long.
7 days	9 plants with first leaves 2½ to 4 inches long.	10 plants; first leaves 2 to 3 inches long.	8 plants; first leaves ½ to 1 inch long.	9 plants; first leaves 1 to 2 inches long.
8 days	6 second leaves in sight.	12 second leaves in sight.	2 second leaves in sight.	3 second leaves in sight.
10 days	Second leaves 2 to 4 inches long.	Second leaves 2½ to 4 inches long.	Second leaves 1 to 4 inches long.	Second leaves 2 to 3 inches long.
13 days	Third leaves in sight.	Second leaves full grown, third leaves not in sight.	Third leaves 0 to 1 inch in length.	Third leves 1 to 1½ inches long.

Concerning varietal differences in susceptibility to actual infection such differences are not definitely established. The writers agree with

Hecke (*14*) and Kirchner (*16*) that bunt liability is not necessarily related to the varietal character of quick germination and rapid initial growth. Two series of tests of several varieties of wheat were made, in which the stage of development was observed daily. The notes on four of these varieties are given in Table 22.

By reference to Tables 20 and 21 it will be seen that Turkey and Florence are the least bunt liable of all varieties tested and that Jones Winter Fife and Chul × Bluestem are extremely susceptible. The plant growth in Florence and Chul × Bluestem is equally rapid, while in Turkey and Jones Winter Fife the growth is equally slow. These tests were performed in the greenhouse. The grain was sown at a depth of exactly 2 inches, under conditions of soil temperature and moisture that were uniform during the period of observation. The grain used for seed was of the same age and was grown on the college farm at Pullman.

It is not the wish here to controvert the view of Tubeuf (*22*, *23*) and Appel and Gassner (*3*) that "the shorter the time between the initial germination and the appearance of the first leaf, the less the liability to infection, providing all other factors are equal." But the results of these experiments indicate that the differences in growth rate are varietal characters not necessarily related to bunt resistance.

SUMMARY.

Wind dissemination of spores was shown in 1915 to be the most important factor in the continued propagation of bunt in the Pacific Northwest, where the biennial crop system is practiced.

Bunt spores lose their viability in 30 to 60 days in moist soil.

Bunt spores in unbroken smut balls retain their viability throughout the winter months, even when subjected to alternate freezing and thawing, and they have produced infection after lying 1½ years in the soil.

When continually subject to the dry air of the laboratory or herbarium, bunt spores retain their germinating power for 12 years and possibly longer.

The minimum, optimum, and maximum germination temperatures for *Tilletia tritici* are, respectively, 0 to 1° C.; 18° to 20° C.; and 25° to 29.1° C.

Wheat sown in soil at a temperature above 20° C. is practically immune from bunt infection from seed-borne spores, but not necessarily from spores already in the soil.

Spores exposed five days to a temperature of 29.1° C. failed to germinate when changed to the optimum temperature.

The presence of free oxygen is necessary to the germination and normal growth of the bunt organism.

The optimum soil-moisture content for infection in the basaltic soil of the Palouse country lies between 16 and 30 per cent.

The fungus may enter the wheat seedling at any point along the coleoptile.

Under experimental conditions infection may obtain after the seedling has produced its first leaf.

There is direct correlation between the depth of sowing and the percentage of infection.

Experimental study of a large number of varieties has demonstrated a wide range of susceptibility to bunt. The degree of varietal

susceptibility is not determined by vigor and rapidity of growth or early ripening.

A large part of the seed wheat sown in the semiarid regions of the western United States is killed by seed treatment, because of threshing injury to the seed coat.

Infection from spores present in the soil is subject to partial control when the seed is treated with copper sulphate or with commercial lime-sulphur applied full strength and allowed to dry. This protection is not afforded by formaldehyde.

Burying the spores below the seed bed by replowing the summer fallow will aid in controlling bunt.

Bunt can be entirely prevented by sowing treated seed before the smut shower and can be largely controlled by delaying the sowing until the saprophytic existence of the organism has terminated.

LITERATURE CITED.

(1) Appel, Otto.
1906. Zur Beurteilung der Sortenreinheit von Squarehead-Weizenfeldern. *In* Deut. Landw. Presse, Jahrg. 33, p. 465–466, fig. 689.

(2) 1907. Veränderung der Ähren von Squareheadweizen durch Steinbrand. *In* Mitt. K. Biol. Anst. Land- u. Forstw., Heft. 2, p. 12, fig. 3.

(3) ——— and Gassner, Gustav.
1907. Untersuchungen über den Brand, insbesondere den Flugbrand des Getreides. *In* Mitt. K. Biol. Anst. Land- u. Forstw., Heft 2, p. 9–12, fig. 2.

(4) ——— and Riehm, Eduard.
1914. Zur Frage der Überwinterung des Steinbrandes im Boden. *In* Mitt. K. Biol. Anst. Land- u. Forstw., Heft 15, p. 6.

(5) Brown, William.
1915. Studies in the physiology of parasitism. I. The action of Botrytis cinerea. *In* Ann. Bot., v. 29, p. 313–348. References, p. 348.

(6) Edler, Wilhelm.
1906. Zur Veränderlichkeit der Squarehead-Zuchten. *In* Fühlings Landw. Ztg., Jahrg. 55, p. 601–606, 2 fig.

(7) Falke, Fr.
1900. Die Dehne'sche Desinfektionsmaschine für Saatgetreide. *In* Landw. Wchnschr. Sachsen, Jahrg. 2, p. 365–367, 374–375, illus.

(8) 1905. Beobachtungen über den Einfluss der Saatgutbeize auf die Keimfähigkeit des Getreides in trockenen Jahren (1904). *In* Illus. Landw. Ztg., Jahrg. 25, p. 479–480.

(9) Gaines, E. F.
1920. The inheritance of resistance to bunt or stinking smut of wheat. *In* Jour. Amer. Soc. Agron., v. 12, p. 124–132.

(10) Grassmann, P.
1886. Die Verluste beim Weizenbau infolge unzweckmässiger Anwendung des Kupfervitriols als Schutzmittel gegen den Schmierbrand. *In* Landw. Jahrb., Bd. 15, p. 293–307.

(11) Harwood, P. M., and Holden P. G.
1892. Smut in oats and wheat. Jensen or hot water treatment. Mich. Agr. Exp. Sta. Bul. 87, 12 p., 5 fig.

(12) Heald, F. D., and George, D. C.
1918. The wind dissemination of the spores of bunt, or stinking smut, of wheat. Wash. Agr. Exp. Sta. Bul. 151, 23 p., 2 fig.

(13) ——— and Woolman, H. M.
1915. Bunt or stinking smut of wheat. Wash. Agr. Exp. Sta. Bul. 126, 24 p., 5 fig.

(14) HECKE, LUDWIG.
1909. Der Einfluss von Sorte und Temperatur auf den Steinbrandbefall. *In* Ztschr. Landw. Versuchsw. Oesterr., Jahrg. 12, p. 49–66, 1 pl. Bibliographical footnotes.

(15) HURD, ANNIE MAY.
1920. Injury to seed wheat resulting from drying after disinfection with formaldehyde. *In* Jour. Agr. Research, v. 20, p. 209–244, 5 fig., pl. 36–41. Literature cited, p. 243–244.

(16) KIRCHNER, OSKAR VON.
1916. Untersuchungen über die Empfänglichkeit unserer Getreide für Brand- und Rostkranheiten. *In* Fühlings Landw. Ztg., Jahrg. 65, p. 1–27, 41–72, 92–137. Literatur, p. 109–111.

(17) NOBBE, FRIEDRICH.
1872. Ueber die Wirkungen des Maschinendrusches auf die Keimfähigkeit des Getreides. *In* Landw. Vers. Stat., Bd. 15, p. 252–275, 4 fig.

(18) POTTER, ALDEN A., and COONS, G. H.
1918. Differences between the species of Tilletia on wheat. *In* Phytopathology, v. 8, p. 106–113, 4 fig. Literature cited, p. 112–113.

(19) SCHROEDER, H. S.
1910. Die Widerstandfähigkeit des Weizen- und Gerstenkorns gegen Gifte und ihre Bedeutung für die Sterilisation. *In* Centbl. Bakt. [etc.], Abt. 2, Bd. 28, p. 492–505.

(20) SHULL, CHARLES A.
1913. Semipermeability of seed coats. *In* Bot. Gaz., v. 56, p. 169–199, 9 fig. Literature cited, p. 197–199.

(21) STEGLICH, B.
1909–11. Die Uebertragung des Weizensteinbrandes auf den Pflanzenbestand der Weizenfelder durch infizierten Stalldünger, Samen und Ackerboden. *In* Fühlings Landw. Ztg., Jahrg. 58, p. 738–742, 1909; 60, p. 54–55, 1911.

(22) TUBEUF, CARL VON.
1901. Studien über die Brandkrankheiten des Getreides und ihre Bekämpfung. *In* Arb. Biol. Abt. K. Gsndhtsamt., Bd. 2, 179–349, 19 fig., pl. 8.

(23) 1902. Weitere Beiträge zur Kenntnis der Brandkrankheiten des Getreides und ihrer Bekämpfung. *In* Arb. Biol. Abt. K. Gsndhtsamt., Bd. 2, p. 437–467, illus.

(24) VOLKART, ALBERT.
1906. Die Bekämpfung des Steinbrandes des Weizens und des Kornes. *In* Landw. Jahrb. Schweiz, Jahrg. 20, p. 445–490, 3 fig. Bibliographical footnotes.

(25) WOOLMAN, H. M.
1914. Stinking smut in wheat. Wash. Agr. Exp. Sta. Pop. Bul. 73, 8 p.

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